

MASTER

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--85-2272

DE85 014072

TITLE THE WNR/PSR FACILITY - NEUTRON PHYSICS CAPABILITIES FROM
SUB-THERMAL TO 800 MEV

AUTHOR(S) P. W. Lisowski, S. A. Wender, and G. F. Auchampaugh

SUBMITTED TO The International Conference on Nuclear Data for Basic and
Applied Science
Santa, Fe, New Mexico, May 13-17, 1985

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article the publisher recognizes that the U.S. Government retains a nonexclusive, royalty free license to publish or reproduce the published form of this contribution or to allow others to do so for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

jsu

THE WNR/PSR FACILITY - NEUTRON PHYSICS CAPABILITIES FROM SUB-THERMAL TO 800 MEV

P.W. Lisowski, S.A. Wender, and G.F. Auchampaugh
Los Alamos National Laboratory, Los Alamos,
New Mexico 87545

Abstract The Weapons Neutron Research facility (WNR) is a versatile pulsed neutron source used in a variety of research programs ranging from fundamental neutron properties with ultra cold neutrons to medium energy charge exchange reaction studies. Here we describe the WNR facility and the improvements presently in progress as the Proton Storage Ring (PSR) becomes operational.

INTRODUCTION

The Weapons Neutron Research facility (WNR)^{1,2,3} has been operational since 1977 as a pulsed spallation neutron source at Los Alamos National Laboratory. At the WNR a part of the 800 MeV proton beam from the Clinton P. Anderson Meson Physics Facility (LAMPF) has been used to either provide a white neutron source for Nuclear Physics and Condensed Matter research or for proton induced reaction studies. At present the facility is being given significantly enhanced capabilities. First, the Proton Storage Ring (PSR), operational in 1985, will provide greatly improved intensity, time structure, and repetition rate for neutron experiments in the thermal and epithermal energy range. Second, an additional target area is being constructed for Nuclear Physics experiments which will take advantage of multiplexed operation and forward angle flight-paths to greatly enhance the fast-neutron flux over that presently available. Finally, an ultra-cold neutron (UCN) source using neutrons from a neutrino production target located south of the WNR/PSR complex is under development. In this paper we plan to review the WNR/PSR operating characteristics illustrated by some recent experimental results.

FACILITY DESCRIPTION

The WNR/PSR Facility is one of several target areas located at LAMPF. LAMPF is an 800 MeV proton linac which simultaneously

P. W. LISOWSKI, S. A. WENDER, AND G. F. AUCHAMPAUGH

accelerates pulsed beams of H^+ and H^- ions with a macroscopic frequency of 120 Hz and a macropulse length of approximately 833 microseconds. Because the first stage of acceleration operates at 201 MHz, the macropulse has a sub-structure consisting of micropulses which are separated by 5 ns. The beam from LAMPF to the WNR can be provided either as macropulses, sections of macropulses, or as macropulses which have been chopped to leave micropulses with a minimum separation of 360 ns. After acceleration, the proton beam is deflected from LAMPF to the WNR/PSR using a pulsed or kicker magnet which will operate at up to 120 Hz.

The layout of the WNR/PSR is shown in Figure 1. Basically, there are four experimental areas, Target-1, a high-current area which is fed by the Proton Storage Ring (PSR), Target-2, a low-current, low-return room with an external proton beam capability, Target-4, a medium-current fast-neutron nuclear physics target area, and an ultra-cold neutron source located above a neutrino physics production facility to the south of the WNR/PSR complex. Neither Target-4 nor the UCN area are shown in Figure 1.

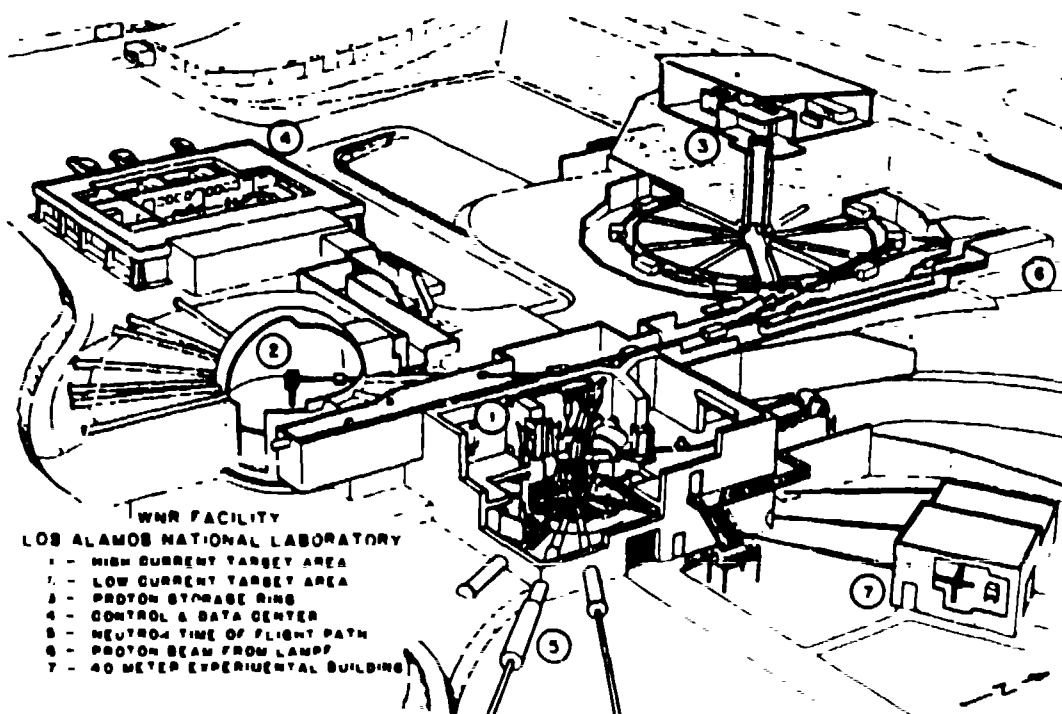


FIGURE 1 The layout of the WNR/PSR facility. The beam from LAMPF enters from the right. The UCN and Target-4 areas are not shown, but are located to the south of the complex along the proton beam line from LAMPF and on an extension of the beam line into the low-current target, respectively.

WNR/PSR FACILITY - NEUTRON PHYSICS FROM SUB-THERMAL TO 800 MEV

Proton Storage Ring

The pulsed proton beam delivered to the WNR directly from LAMPF is too low in peak intensity to allow the use of short pulses at a low enough repetition rate to be well suited to condensed matter and low-energy neutron physics research. The PSR acts as a proton accumulator, converting the long linac pulses into appropriately short, very intense bursts at a low repetition rate. This then allows time-of-flight experiments with low-energy neutrons to be conducted with sufficient pulse spacing to avoid frame overlap through the neutron energy range of interest. Although fast-neutron experiments will not use the PSR beam at the present time, improvements to the LAMPF chopper, beam transport system, and beam multiplexing system as a result of PSR technology have made a dramatic increase in the beam current available for fast-neutron physics. This may be seen in Table 1 which compares proton beam operating conditions for the WNR with and without the PSR.

TABLE 1 LAMPF and WNR proton beam characteristics

	LAMPF	PRE-PSR MACRO-PULSE MODE	PRE-PSR MICRO-PULSE MODE	POST-PSR MACRO-PULSE MODE	POST-PSR MICRO-PULSE MODE
PROTONS PULSE	5.2×10^{13}	2.8×10^{11}	5.0×10^7	5.2×10^{13}	3.0×10^8
PULSE WIDTH	833 μ S	5 μ S	200 ps	270 ns	200 ps
REPETITION RATE	120 Hz	120 Hz	10000*	12 Hz	58000*
PROTONS SECOND AVERAGE	6.25×10^{15}	3.4×10^{11}	5.0×10^{11}	6.25×10^{14}	1.8×10^{13}
AVERAGE PROTON CURRENT	1 mA	5.4 μ A	80 nA	100 μ A	28 μ A

* - WITH 1 μ S SEPARATION DURING LAMPF MACROPULSE

During PSR/WNR operation, the H^+ beam is deflected from the linac by a pulsed magnet into a drift tube leading to the WNR/PSR complex. A second pulsed magnet can then deflect the beam into the PSR. In order to transport the beam into the PSR a stripper magnet is used to selectively remove one electron converting the H^+ to H^0 with high efficiency allowing the beam to enter the PSR ring through a magnet. Beam is then accumulated and returned to line-D after a foil stripper which converts the beam to H^+ for transport to the WNR targets.

Construction of the PSR was begun in early 1982 and the complex is currently in operation. A progressive current increase is planned with up to 100 microamperes planned for the WNR target by the fall of 1986.

Target-1

The high-current target area has recently been upgraded⁴ to accept as much as 200 microamperes of 800-MeV proton beam. Here the target-moderator and flight path geometry has been optimized to use the PSR beam structure of 270 ns at 12 Hz to produce an intense thermal and epithermal source, useful for both condensed matter and low-energy neutron nuclear physics studies.

This area has a split target-moderator-reflector (TMR) assembly located in the center of a 2-m high, 1-m diam. cylindrical void, and surrounded by a 4.2-m thick iron and laminated iron-concrete biological shield. The TMR geometry will eventually permit up to 17 neutron flight paths to operate simultaneously with six separately optimized moderators. As shown in Figure 2 the neutron flight paths view the moderators at 90° to the incident proton beam, and the target is split so that experiments do not view the central neutron-producing target directly, thus reducing fast neutron background. Initial moderators will include two conventional poisoned ambient water

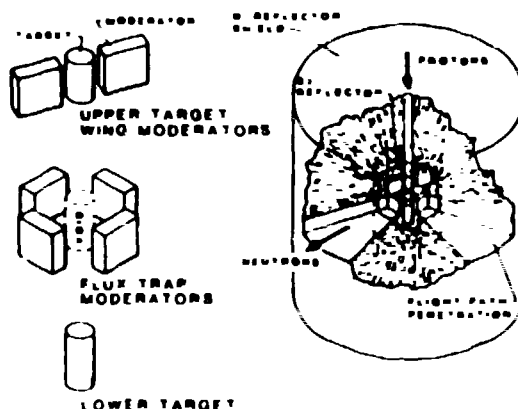


FIGURE 2 The WNR high-current TMR configuration. The present arrangement has twelve flight paths viewing the flux-trap moderators. Future flight paths would view wing moderators which would be installed in the upper target position

moderators, a 20° K liquid H₂ cold moderator, and a high-resolution moderator decoupled at 3 eV which has been optimized for epithermal neutron experiments. For the ambient water moderators preliminary calculations of neutron intensities and pulse widths for the flux-trap geometry are shown in Figures 3 and 4. With this choice, the spectrum is Maxwell-Boltzman at thermal, but is proportional to 1/E at epithermal energies. In addition, the pulse width is inversely proportional to velocity at epithermal energies so that Time-of-Flight (TOF) experiments have constant energy resolution in that energy regime.

Target-2

The existing low-current target, labelled as target-2 in Figure 1, is shielded for up to 100 nanoamperes of proton beam. This room is designed to reduce room return by having a low-mass floor and a 6-meter wall-to-center spacing. Because of the flexibility of design, many different experiments have been performed in this

WNR/PSR FACILITY - NEUTRON PHYSICS FROM SUB-THERMAL TO 800 MEV

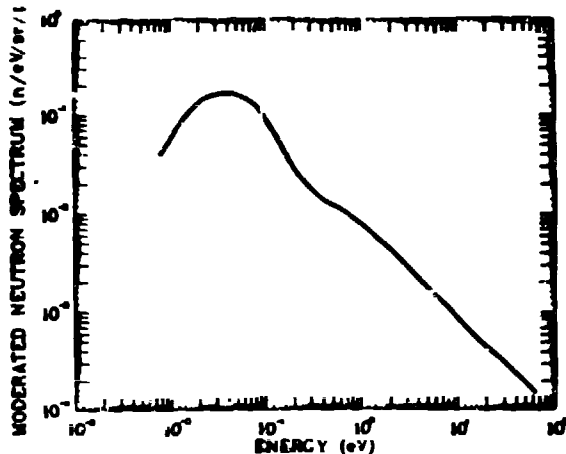


FIGURE 3 Calculated neutron spectrum emitted at 90° to the moderator surface from the WNR flux-trap TMR.

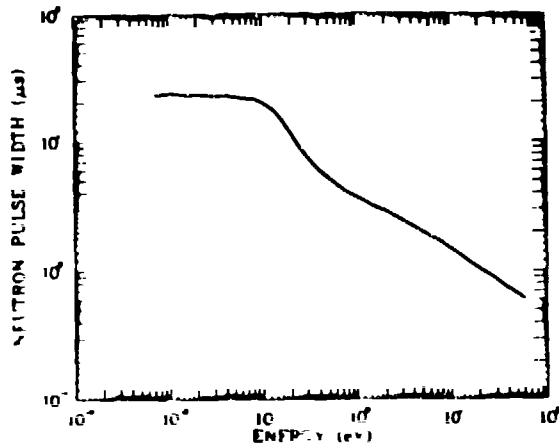


Figure 4 Calculated pulse widths of neutrons emitted from the WNR flux-trap TMR.

area. Most recently, theoretical predictions of target-moderator neutron output for the upgraded WNR/PSR target system have been tested⁵ and a variety of proton-induced reaction studies⁶ have been carried out.

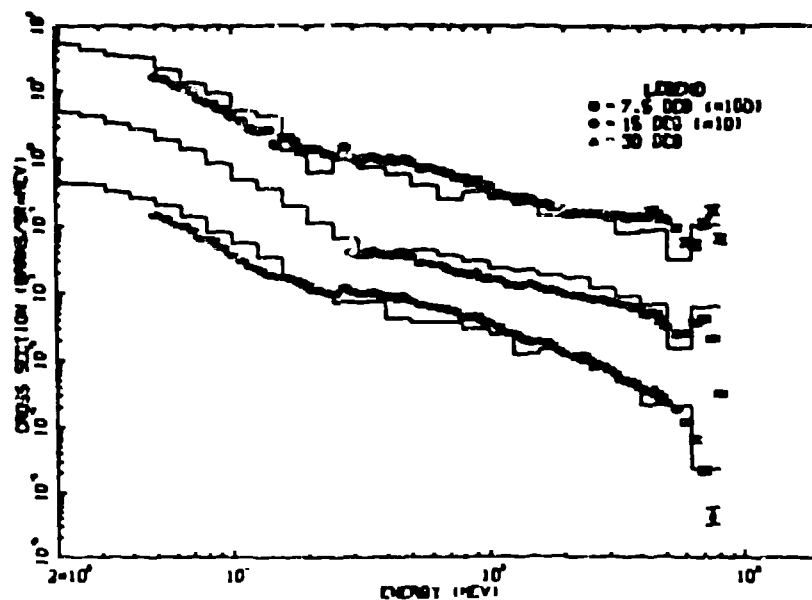
The target-moderator measurements⁵ were performed using a vertical, well shielded 5.6-m flight path located in the center of Target-2. The neutron detection scheme for those experiments has been to use a BF_3 proportional counter to detect moderated neutrons in the line-of-sight and a ^3He counter to measure the neutron intensity and time profile by scattering from a pyrolytic graphite crystal.

Measurements of fast neutron spectra using the chopped, or micropulse beam have been made using a target changer placed at the center of the room with neutron detectors positioned outside on flight paths of approximately 30 meters. These experiments have typically been performed to test Intranuclear Cascade calculations. For such experiments angular distributions at angles of 7.5° , 15° , 30° , 45° , and 60° are possible. Shown in

P. W. LISOWSKI, S. A. WENDER, AND G. F. AUCIAMPAGH

Figure 5 are double differential cross sections for the $^{238}\text{U}(\text{p},\text{xn})$ reaction at angles of 7.5° , 15° , and 30° recently obtained⁶ using Target-2.

By removing the beam pipe and allowing the proton beam to pass through the air, it is possible to have an external proton beam in the center of the room for various test set-ups and irradiations. For example, beam-pulse timing tests⁷ which measured the proton micropulse width to be 200 ps FWHM were performed by measuring the time spread of the Cherenkov light from a lucite rod coupled to a photodiode inserted in the beam in this area.



REPRODUCED FROM
BEST AVAILABLE COPY

FIGURE 5 Double differential cross sections for $^{238}\text{U}(\text{p},\text{xn})$ at 800 MeV obtained using Target-2. The histograms are Intranuclear Cascade calculations.

Target-4

In order to provide a source of fast neutrons for Nuclear Physics experiments, a new white source facility is under construction at the WNR/PSR. A layout of this area is shown in Figure 6 and can be seen to be located on an extension of the beam transport system for Target-2. In this facility, there are three important features. First, the flexibility of the existing Target-2 arrangement will be maintained by using an 8° bending magnet to elevate the new white-source flight paths above those of Target-2, as illustrated in Figure 7. Second, a high-resolution small-angle (p,n) experimental facility located along Line-D at WNR, which had to be moved because of conflict with the Neutrino Facility, can be

WNR/PSR FACILITY - NEUTRON PHYSICS FROM SUB-THERMAL TO 800 MEV

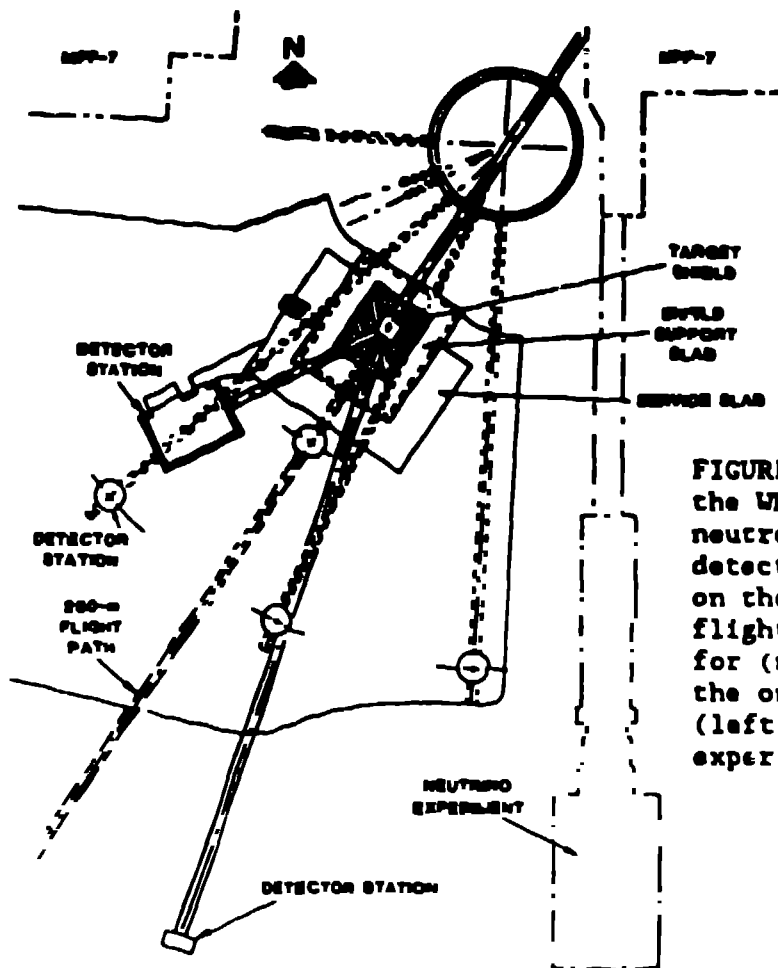


FIGURE 6 The layout of the WNR Target-4 white-neutron source. The detector station located on the 30° (right) flight path is planned for (n,x) experiments, the one on the 15° (left) for (n,p) experiments.

operated simultaneously with the white source in this area. Third, the neutron flight paths for the new facility view the production target at forward angles instead of 90° as in the old Target-1 arrangement, thus providing a source extending to nearly 800 MeV with greatly increased neutron intensity above about 20 MeV.

Target-4 will have seven flight paths viewing the production target at angles ranging from 15° to 90° . The neutron source strengths at angles of 30° and 112° are shown in Figure 8. These results were computed from measured thin-target cross sections⁸ for 15-cm thick targets. Comparing 30° and 112° results for copper shows that the source strength for forward angles remains nearly constant to 500 MeV; furthermore, there is more than an order of magnitude more intensity for neutrons with energies above 60 MeV. The solid curve in Figure 8 gives the yield for the most intense laboratory source of monoenergetic neutrons, the $H(t,n)$ reaction. Here the calculation⁹ was performed with a pulsed beam current of 0.5 microampere of tritium beam. The more

P. W. LISOWSKI, S. A. WENDER, AND G. F. AUCHAMPAUGH

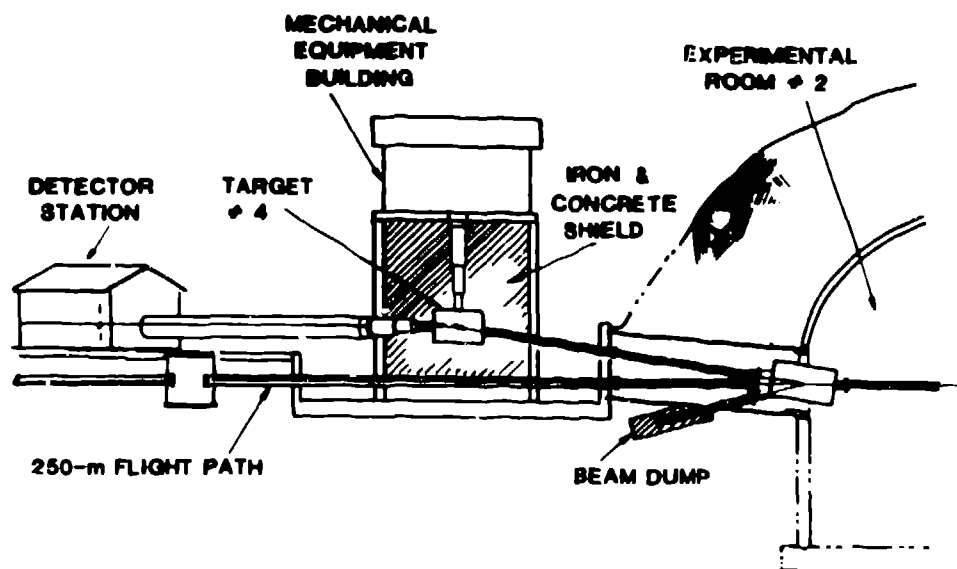


FIGURE 7 A side view of WNR Target-4. The proton beam is deflected 8° up into Target-4 from Target-2. The target changer for high resolution (p,n) experiments is located in the magnet. For measurements at angles greater than 8° , the proton beam is bent down into the beam dump.

common 14 MeV source, the d-T resonance reaction would yield about 10^8 n/s/sr/MeV. For comparison with an existing white source facility, Figure 9 shows the number of neutrons/cm²/sec versus neutron energy for ORELA¹⁰ and WNR Target-4. In this comparison, similar to that in Reference 3, the overall timing for detected neutrons was taken to be 1 ns for WNR and 5 ns for ORELA. The numbers in parenthesis give the number of pulses and the flight path needed to maintain an energy resolution of 8.8×10^{-4} . Other parameters used in the calculation are given in Table 2.

Target-4 construction is planned to start in late May of 1985 with three flight paths to be implemented in time for experiments to be performed during the 1986 LAMPF Cycle. The three flight paths to be implemented are a 250-m flight path for high resolution medium energy (p,n) reaction studies, a 15-m flight path at 30° for fast-neutron capture and gamma-production experiments, and a 65-m flight path at 15° for (n,p) experiments. The (p,n) and (n,x γ) experiments^{11,12,13} have already produced unique nuclear physics information from initial experiments carried out at WNR. Figure 10 shows cross section angular distributions for $^{12}\text{C}(p,n)$ at three angles.¹¹ These spectra illustrate the ability of experiments at WNR to cover a broad range of nuclear excitation. The spectra on the right show a high-resolution plot of the low momentum-transfer region showing for the first time for (p,n) reactions at 800 MeV, a resolved nuclear transition. The spectra on the left are low resolution

WNR/PSR FACILITY - NEUTRON PHYSICS FROM SUB-THERMAL TO 800 MEV

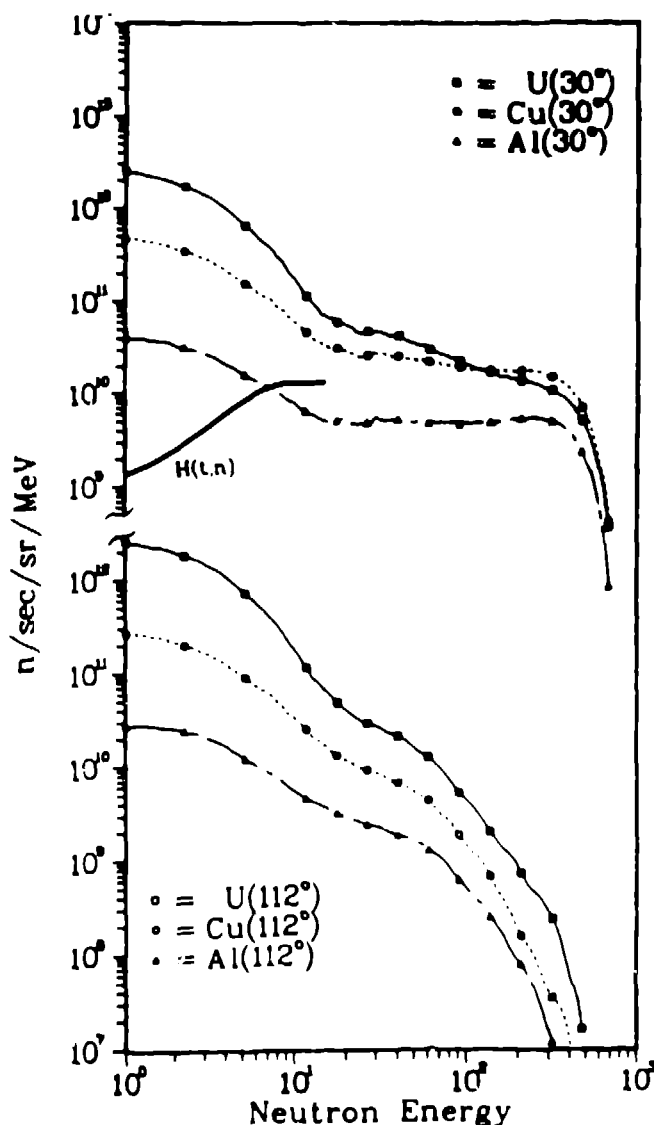


FIGURE 8 Calculated neutron source strengths for angles of 90° (top) and 112° (bottom) for 1 microampere of 800 MeV proton beam incident on 15-cm thick targets of different materials. The solid curve labelled $H(t,n)$ is calculated for an 0.5 microampere tritium beam producing a monoenergetic neutron beam

plots of the same data but extending to the delta-production region near 1050 MeV/c.

Ultra Cold Neutron Source

Located to the south of the WNR/PSR complex as seen in Figure 6, there is a neutrino experiment. The beam dump for this area was designed to be a very efficient thermal neutron source. Here, one Hz of the beam used to produce neutrinos in a carbon target is planned to be steered directly onto a tungsten beamstop. A vertical neutron flight path, installed and tested in 1984 permits thermal neutrons from an adjacent moderator to be extracted and used. The UCN are then produced by Doppler shifting 400 meter/second neutrons by Bragg reflection from a moving crystal. The apparatus for this was developed at Argonne National

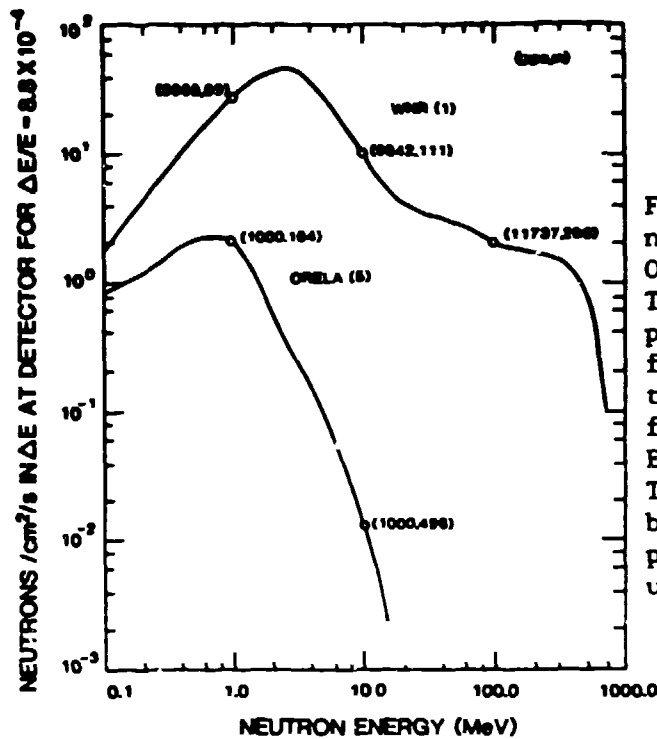


FIGURE 9 Comparison of neutron fluxes from the ORELA and WNR facilities. The quantities in parenthesis represent the frequency and flight path to achieve maximum neutron flux in the energy interval E for the given resolution. The quantity in parenthesis by the facility name is the pulse width in nanoseconds used in the calculation.

TABLE 2 Machine parameters used to calculate Figure 9

FACILITY	PULSE FREQUENCY (Hz)	AVERAGE BEAM CURRENT OR POWER	TARGET
ORELA	1000	10 kW	Ta, $\Delta L = 22$ cm
WNR	25000	<2 μ A	^{235}U 15-cm LONG $\theta = 30^\circ$ $\Delta L = 22$ cm

Laboratory and is in place at the WNR. Figure 6 shows a layout of the neutrino area with the UCN flight path near the center.

Although several experiments have been proposed for the UCN, a measurement or lowering of the limit of the magnitude of the electric dipole moment (EDM) of the neutron is the most important. For EDM measurements of the type planned here the accuracy of the result depends on the number of neutrons stored in a bottle. For this experiment the number stored asymptotically approaches the peak neutron flux. At spallation sources such as WNR, the peak flux is expected to be an order of magnitude better than from any reactor yet built. A further advantage will come from running a cold moderator more closely coupled to the spallation source than is possible in a reactor, thus increasing the efficiency of neutron moderation. A density of 120 UCN/cm³ is expected if the PSR beam is used with an optimized UCN bottle. This may be compared with the density of 0.05 UCN/cm³ reported in 1984 by Pendlebury et al.¹⁴

WNR/PSR FACILITY - NEUTRON PHYSICS FROM SUB-THERMAL TO 800 MEV

$^{12}\text{C}(p,n) \quad T_p = 800 \text{ MeV}$

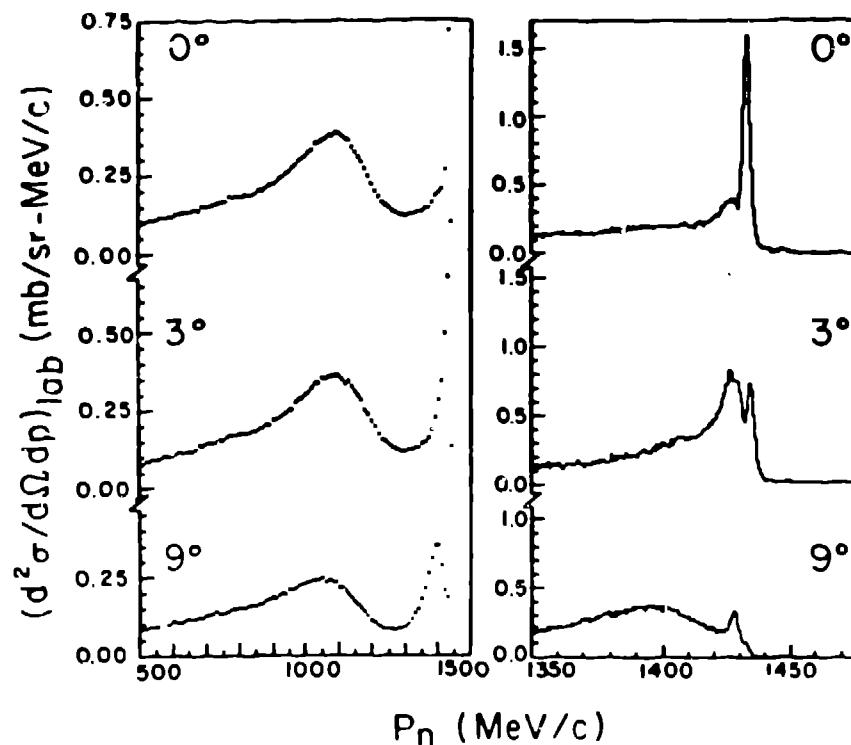


FIGURE 10 At left: low resolution $^{12}\text{C}(p,n)$ data showing the delta-production region near 1050 MeV/c. At right is an expanded spectrum in the region of the ground-state transition.

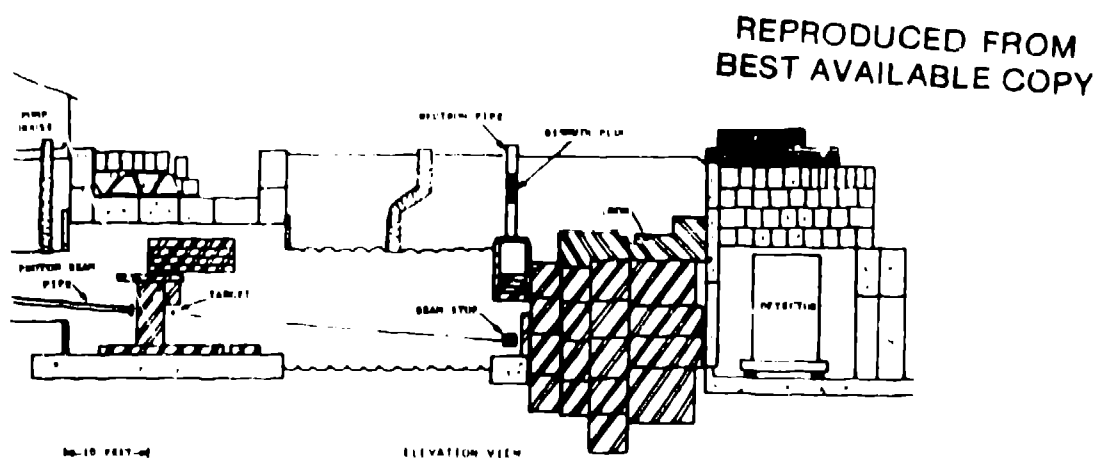


Figure 11 Elevation view of the neutrino facility located at the WNR. The neutron flight path to the UCN apparatus is indicated by the label NEUTRON PIPE near the center of the drawing.

P. W. LISOWSKI, S. A. WENDER, AND G. F. AUCHAMPAUGH

SUMMARY

The WNR/PSR Facility will be operational during 1985 for Condensed Matter research as the most intense pulsed-neutron source in the world. By spring of 1986 the fast-neutron capabilities will be greatly enhanced with the addition of a multi-use white-neutron source for measurements in the 1-500 MeV range, and a 250-m flight path for (p,n) reaction studies. This facility will be heavily used by the Los Alamos staff for a variety of basic and applied research, but proposals from outside collaborators or groups wishing to conduct experiments at the WNR/PSR are encouraged.

REFERENCES

1. G.J. Russell, P.W. Lisowski, S.D. Howe, N.S.P. King and M.M. Meier, in Nuclear Data for Science and Technology, International Conference, Antwerp, 1982, edited by K. Boeckhoff (Reidel, Dordrecht), p. 831.
2. G.J. Russell, Los Alamos National Laboratory Report, LA-UR-84-778 (1983).
3. G.F. Auchampaugh in Cross Sections for Technology, International Conference, Knoxville, 1980, edited by J.L. Fowler, C.H. Johnson, and C.D. Bowman, (NBS Special Publication No. 594), p. 920.
4. G.J. Russell, Los Alamos National Laboratory Internal Report, TN-GJR/P9-006 (1983).
5. G.J. Russell, M.M. Meier, H. Robinson, and A.D. Taylor, in Proceedings of the Fifth Meeting of the International Collaboration on Advanced Neutron Sources (ICANS-V), Juelich, 1981.
6. M. M. Meier, D. Holtkamp, G. L. Morgan, H. Robinson, G. Russell, R. Whitaker, W. Amian, and N. Paul, in International Conference on Nuclear Data for Basic and Applied Science, Santa Fe, 1985, contribution JC23.
7. Project Summary Los Alamos National Laboratory Support Program, EGG 1183-2458, 44 (1982).
8. S. D. Howe Ph.D Thesis, University of Kansas, 1975 (unpublished).
9. M. Drogos Los Alamos National Laboratory Memorandum P-3/85-247 (1985).
10. E. R. Rae and W.M. Good, in Experimental Neutron Resonance Spectroscopy, edited by J. A. Harvey (Academic Press, New York, 1970), Chap. 1, pp. 1-99.
11. N.S.P. King, P.W. Lisowski, G.L. Morgan, P.N. Craig, R.G. Jeppesen, D.A. Lind, J.R. Shepard, J.L. Ullman, C.D. Zafiratos, C.D. Goodman, and C.A. Goulding, to be published.

WNP/PSR FACILITY - NEUTRON PHYSICS FROM SUB-THERMAL TO 800 MEV

12. S.A. Wender, and G.F. Auchampaugh, International Conference on Nuclear Data for Pure and Applied Science, Santa Fe, 1985, contribution JB08; C. R. Gould, J. Dave, G.E. Mitchell, P. Ramakrishnan, G.F. Auchampaugh S.A. Wender and R.C. Little, ibid. contribution AD04.
13. S.A. Wender and G.F. Auchampaugh, in The Fifth International Symposium on Capture Gamma-ray Spectroscopy and Related Topics, Knoxville, 1984, edited by S. Raman (American Institute of Physics, New York), p. 483.
14. J.M. Pendlebury et al., Phys. Lett. 136B, 327 (1984).